Development of a Lunar Dust Reactivity Sensor

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During the Apollo missions, NASA discovered that the pervasive lunar dust caused a multitude of problems for the astronauts. The dust obscured vision, coated and abraded surfaces, clogged equipment, and caused false instrument readings. As various space agencies make plans to return to the moon, one of the biggest concerns might be that of lunar dust inhalation by the astronauts upon entering a lunar habitat or landing vehicle. Astronauts described lunar dust as having a “gunpowder-like smell,” and at least one astronaut complained of “lunar dust hay fever” after inadvertently inhaling some dust.

On the harsh surface of the moon, lunar soil is constantly being formed and modified by micrometeorite (< 1 millimeter [mm]) bombardment and interactions with solar-wind particles. This creates particulates with highly fractured surfaces that contain a high number of free radicals able to react with those things with which it comes into contact, such as the human respiratory system. If this occurs, reactive oxygen species, such as hydroxyl radical, superoxide, and hydrogen peroxide, may be produced. These reactive oxygen species could cause damage to cells, as seen with the effects of freshly fractured quartz.

NASA Johnson Space Center (JSC) previously developed a technique for testing the reactivity of lunar dust in solution. This method takes advantage of a change of fluorescence emission of the terephthalate anion when it is hydroxylated in solution. The fluorescence increase seen with increasing hydroxyl radical concentration is linear, allowing us to make direct comparisons of reactivity between different concentrations of an individual dust or the same concentration of different dusts. Using this procedure, the JSC team tested the reactivity of ground lunar soil and compared it to ground lunar dust simulant, ground quartz, and unground lunar dust (figure 1). The team determined that ground lunar dust was approximately three to four times more active for hydroxyl radical generation than ground lunar simulant and approximately eight times more active than ground quartz. Grinding of the lunar dust resulted in an increased reactivity of approximately 10 times as compared to unground lunar dust. Further testing showed that the increased reactivity was due to the presence of iron nanoparticles residing in the amorphous surface rims of the lunar dust.

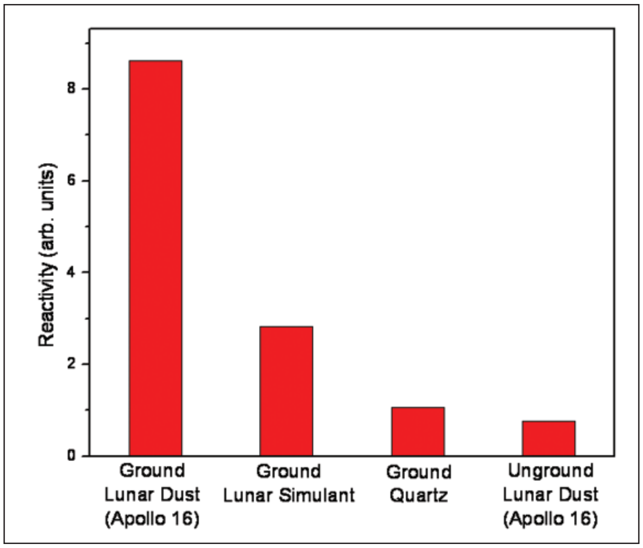

Fig. 1. *Relative changes in the production of hydroxyl radicals in aqueous solution by different dusts.*

This project was aimed at the development of a novel sensor for the determination of lunar dust reactivity in a matrix of humidified air or aqueous solution. Understanding the reactivity of lunar dust will aid in the development of mitigation techniques for lunar dust inhalation. The sensor described here was initially based on a previous NASA-designed sensor to monitor dissolved oxygen levels in solution. That system used a light-emitting diode (LED) to excite a fluorescent dye, and then measured the fluorescent emission. The presence of oxygen would quench the fluorescence, providing a sensitive monitor of the oxygen concentration. The plans for the present sensor are aimed to develop a similar platform, using JSC’s novel fluorescence technique for determining the reactivity of lunar dust.

Initial work focused on the development of a sturdy optical system, capable of efficiently collecting photons emitted from the test solution while minimizing interference from stray light. The optical setup used for the current

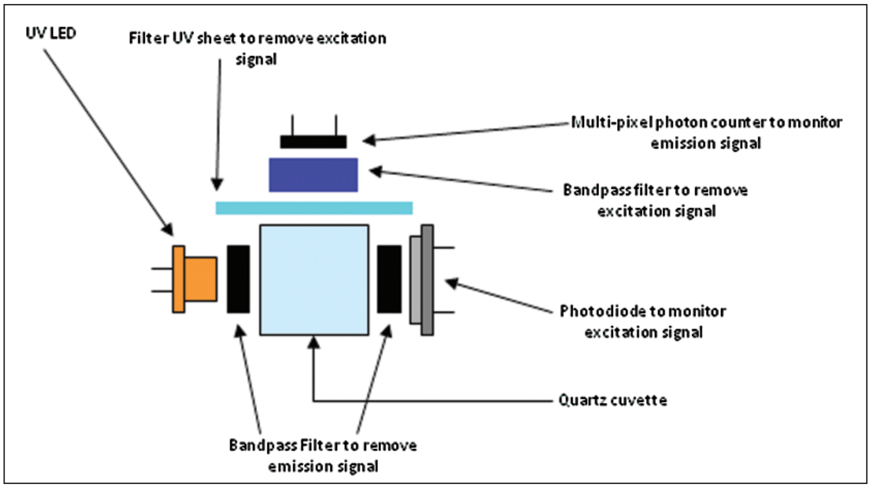

Fig. 2. *Optical schematic of lunar dust reactivity sensor.*

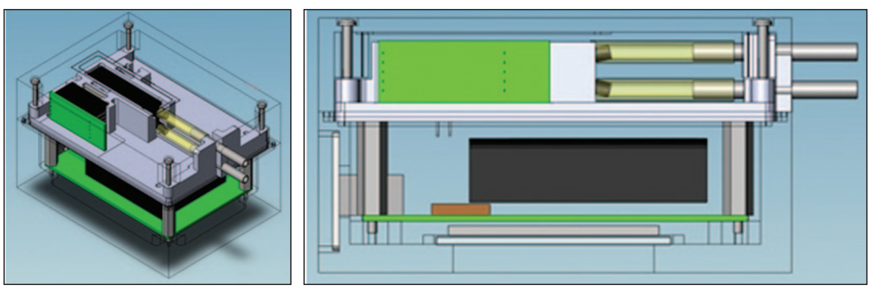

Fig. 3. *Design of the completed lunar dust reactivity sensor.*

sensor (figure 2) consists of a quartz cuvette filled with the solution to be tested, a 320 nanometer (nm) ultraviolet (UV) LED excitation source, and photodiodes to collect (individually) both excitation and emission photons. The emission is collected at a right angle to reduce the amount of excitation light reaching the emission photodiode. The emission detector is also protected by band-pass filters, which only transmit certain wavelengths of light. The power consumption of the UV LED used for testing was on the order of 100 milliwatts. This is in contrast to larger (and more powerful) UV lamps typically used for fluorescence measurements that require several watts of power. It is this low power consumption and small size that makes it possible to produce this compact sensor. The use of multiple photodiodes in the platform serves two functions. First, the emission signal can be normalized against the excitation signal to account for changes in the source output. Second, the excitation signal can be monitored to check the health of the UV LED.

The mechanical design of the sensor (figure 3) consists of three pieces: a base containing the optics assembly (cuvette, UV LED, optical filters, photodiodes); a bottom case containing electronics (shown in green), a battery compartment (shown in black) containing 3 AA batteries and a liquid crystal display panel; and a top cover that encloses the optics to provide a light sealed chamber. Removing stray light is important, as any additional photons could raise the background fluorescence. Tubes attached to the cuvette on one side protrude through the lid to permit flow through of the test fluid.

The JSC team performed a test of the capabilities of the sensor with ground lunar dust simulant and ground quartz at different concentrations, as well as background fluorescence measurements with an empty cuvette and one filled with water. The data shown in figure 4 were collected using an acquisition time of 100 seconds. As shown in the figure, the addition of water to the cuvette slightly increases the background signal. When either quartz or lunar dust simulant mixtures are introduced into the cuvette (the mixtures are filtered prior to entering the sensor), higher emission intensities are found, and the signals continue to increase with increasing dust concentration.

The dust concentrations used for the tests shown in figure 1 were 4 milligrams/milliliter (mg/mL), the lowest concentration used in the sensor testing. For the lunar dust simulant, this concentration produced an output signal

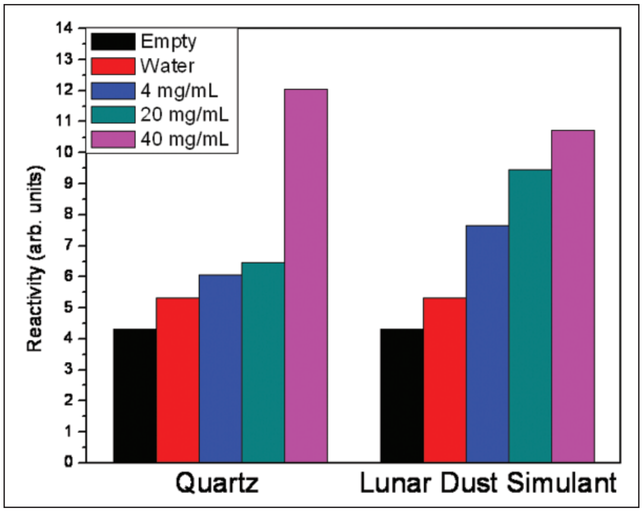

Fig. 4. Reactivity of quartz and lunar dust simulant measured by the lunar dust reactivity sensor.

approximately 40% higher than the water background, while the quartz produced an approximately 10% higher signal than water. The relative reactivities of these two dusts, as measured by the sensor, are similar to those measured with a standard laboratory fluorimeter. Because the fluorescence intensity produced by the quartz mixture at this concentration is so close to that of the background, the operational limit of detection would be greater than 4 mg/mL. However, if a more reactive lunar dust were tested, the platform should be capable of producing usable signal levels at this concentration.

In summary, the JSC team developed and tested a sensor platform capable of monitoring the reactivity of dust on the lunar surface during future human habitation. This sensor uses the change in fluorescence of a probe compound upon hydroxylation to determine the amount of hydroxyl radicals produced by lunar dust. While the sensor was developed for lunar dust testing, its small volume and mass would make it useful for terrestrial applications as well, such as in mining operations.